Section 206 - Flood Plain Management Services

Kennebec River Flow Gaging Needs Assessment, Maine

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This study, conducted under the authority contained in Section 206, Flood Plain Management Services, was prepared at the request of the State of Maine's State Planning Office. The study was prepared primarily by National Weather Service and US Geological Survey. The Scope of Work for this project was prepared by the Army Corps of Engineers. The purpose of the report was to determine the impacts of removing streamflow gages in the Kennebec River basin on the National Weather Service's flood forecasting abilities, and to determine what effect this might have on emergency response related to flooding.

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EXECUTIVE SUMMARY

Maine's cooperative stream gaging program was targeted for elimination in the 1994-1995 annual state budget review. If eliminated, three of the four stream gages used by the National Weather Service (NWS) to forecast floods and issue timely flood warnings in the Kennebec River basin would have been removed from service, and the coordination of the snow survey by the US Geological Survey (USGS) would have ceased. Funding for the program was restored at the last minute, but concerned users of the NWS flood forecast program requested an evaluation of potential impacts due to the loss of the streamflow and snow survey data.

This report, prepared primarily by NWS and USGS, assesses the impact of discontinuing the cooperative stream gaging and snow survey coordination program on the NWS flood forecast program. At present, there are two river flood forecast points: the Kennebec River at Skowhegan, and the Kennebec River at North Sidney/Augusta. The report determines if specific numeric forecasts would likely continue to be provided at the forecast points with the reduced gage network, or if categorical (non-numerical) flood forecasts would be issued instead. The report also examines, at a cursory level, the sufficiency of the NWS flood forecast program in the Kennebec River basin, and the impacts to the end users including flood plain occupants, business-owners and those responsible for emergency response activities.

The Maine State Planning Office requested that the Army Corps of Engineers (Corps) prepare this report to assess the impacts to flood warning caused by the proposed gage closure and snow survey data collection discontinuance. The Corps enlisted the USGS and the NWS to perform the evaluation and write this report.

The three gage sites targeted for elimination in the Kennebec River basin were:

1. Carrabassett River near North Anson;
2. Sebasticook River near Pittsfield; and,
3. Kennebec River at North Sidney.

All three sites are presently used to forecast floods at North Sidney/Augusta and issue river flood warnings to the public. Impacts of the gage elimination and discontinuance of snow survey data collection are summarized as follows:

1. NWS would likely continue to provide numeric forecasts and flood warnings at North Sidney/Augusta. The level of accuracy of the forecasts, however, would decrease significantly, with errors of several feet possible.

2. The flood forecast and river flood warning lead time at Augusta would be reduced by 18 hours, from 24 hours at present to 6 hours without the gages.

3. The reduction in warning time would likely result in a very significant increase in damages in the lower Kennebec River basin. Of particular importance are stock and contents of buildings and vehicles, which could be moved out of the path of the damaging floodwaters if sufficient warning is provided.

4. There would be little impact to the forecast at the Skowhegan gage because flow information provided by Central Maine Power Company for Wyman Lake on the Kennebec River at Bingham is sufficient to allow a specific numeric forecast at Skowhegan.

5. The absence of the snow water equivalent data would make accurate forecasting difficult in the spring, the time of year when the most damaging floods have occurred in Maine. Snow may account for several inches of runoff, which could translate to several feet added to the river's flood stage.

6. The assessment of the current NWS flood forecasting program in the Kennebec River basin revealed that the establishment of a river flood stage and the dissemination of river flood forecasts and warnings may be provided for the Sebasticook River at Pittsfield using the current gage configuration. Average annual flood damages are $95,900 in Pittsfield (US Army Corps of Engineers, 1989).

7. The development of flood forecast procedures should be investigated for four damage areas in the Kennebec River basin having over $975,000 in annual flood damages.

8. A simplified cost approximation technique was employed to determine the likely increase in flood damages at Augusta and at Hallowell due to reduced flood warning time. The analysis indicated that average annual flood damages would likely increase by $44,000 at Augusta and by $25,000 at Hallowell. No attempt was made to estimate increased damages at other locations. During any particular flood, the total flood damages would be many times the average annual values.

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1.0 INTRODUCTION

Recent budget shortfalls in Maine have led to major cuts in the annual appropriations for many State programs. The US Geological Survey (USGS) cooperative streamflow data program was targeted for elimination for the 1994-1995 budget cycle. The funding of 14 streamflow gages throughout the state and the statewide snow-survey coordination program would have been cut. Just before the budget was passed, the funding was restored, but the threat of elimination of this data caused concern among the diverse groups of data users that rely on information from this program. The Maine State Planning Office requested that the Army Corps of Engineers (Corps) complete an assessment of the streamflow gaging program in the Kennebec River basin, looking in particular at the impact of a reduced stream gaging network on flood forecasting. Since three out of the four gages used by the National Weather Service (NWS) for river and flood forecasting in the basin were targeted for elimination, the Corps hired the NWS and USGS to assess the impact of the gage closures on flood forecasting. NWS and USGS prepared this report, with the exception of Chapter 6, Uses of Flood Warning Information for Flood Damage Reduction and Floodplain Evacuation, which was prepared by the Corps.

The assessment of the impacts of the gage closures was done by identifying where streamflow data is, or has been, collected, and determining the effect of eliminating streamgages on flood forecasting capabilities in the Kennebec River basin. A review of NWS river forecast operations, an identification of gaps in the flood forecasting network, a discussion of uses of the forecasts for emergency preparedness purposes, and a summary of other uses of the data are included in the study.

2.0 AUTHORITY

This study was funded under the authority provided by the COE Section 206 Flood Plain Management Service program. The scope of work for the project was prepared by the Corps. The report was prepared under contract by the NWS Eastern Region Hydrologic Services Division in conjunction with the USGS Water Resources Division office located in Augusta, Maine.

3.0 KENNEBEC RIVER BASIN

3.1 Hydrology

The Kennebec River basin, located in central Maine, has a drainage area of 6000 square miles (excluding the Androscoggin River). This area represents almost one-fifth of the total land area of Maine. Figure 1 shows the basin location and some of the key features. The Kennebec River originates at the outlet of Moosehead Lake and flows generally south for about 165 miles to the Atlantic Ocean. The major tributary in the headwaters is the Moose River (722 mi^2) which represents 57 percent of the drainage above the outlet of Moosehead Lake (1268 mi^2). Major downstream tributaries include Dead River (874 mi^2), Carrabassett River (401 mi^2), Sandy River (596 mi^2) and Sebasticook River (946 mi^2), which together comprise 47 percent of the total basin drainage area.

There are numerous run-of-river hydroelectric generating facilities along the main stem of the Kennebec, and on the Sebasticook, Messalonskee and Cobbosseecontee tributaries. Indian Pond and Wyman Lake have limited storage capacity used for daily or weekly fine-tuning of water-use needs downstream. There is 1,122,100 acre-feet of storage in the Kennebec Basin above Wyman Lake, with 1,017,300 acre-feet (89 percent) contained in three large lakes: Brassua, Moosehead, and Flagstaff. Major reservoir storage in the basin is summarized in Table 1.

Table 1 Major Reservoir Storage

Reservoir	D.A. (mi^2)	Storage (ac-ft.)	Storage(%)
Brassua	716	196,500	17
1st Roach	70	21,500	2
Moosehead	1268	544,800	49
Indian Pond	1384	15,800	1
Flagstaff	516	276,000	25
Wyman	2715	67,500	6
Total	--	1,122,100	100

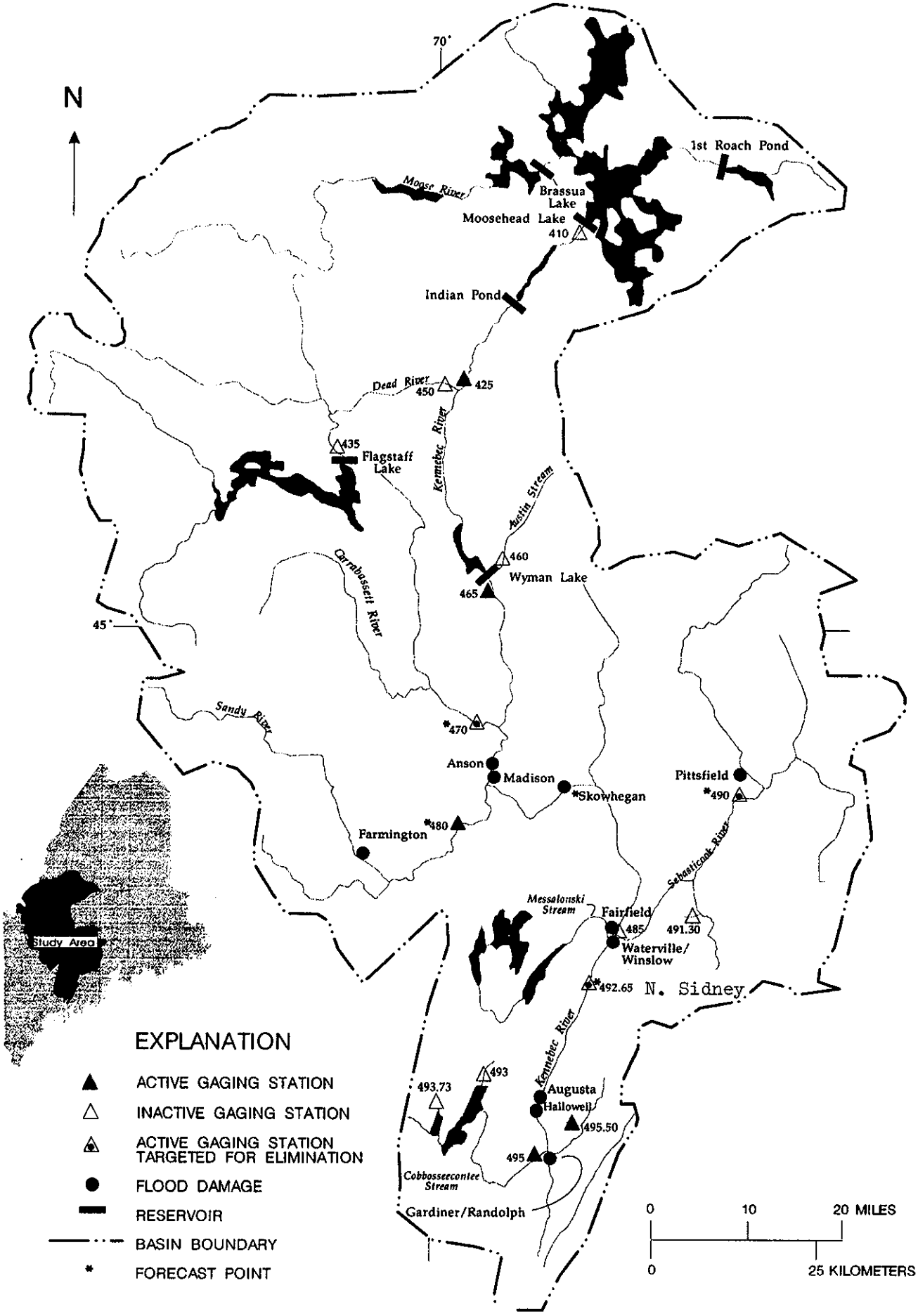

Figure 1.--Kennebec River basin.

3.2 US Geological Survey Data Collection

Streamflow data has been collected, compiled and stored by the USGS at 22 sites in the Kennebec River basin, with eight stations presently in operation. Table 2 lists active and inactive sites where at least 10 years of data have been collected. Sites with less than 10 years of daily values generally cannot be used in statistical analyses or modeling efforts, and therefore are not listed.

3.3 Uses of Data

Streamflow data from these gages are used for areal assessments of water resources, operation of reservoirs and hydro-generation facilities, river flow forecasting, waste-load permitting, water-quality monitoring, legal requirements, design of hydraulic structures, and research. The addition of satellite and/or telephone telemetry at the gaging sites allows for "real-time" indication of stage and flow data, which allows for more timely day-to-day forecast operations, and instantaneous flow monitoring and forecasting during extreme hydrologic events such as floods and droughts. Gages equipped with satellite telemetry provide 15-minute interval data every 3 or 4 hours, and telephone equipped gages can be interrogated at any time. Stream gage measurements that are available nearly instantaneously from the time they are taken are considered measurements in "real-time".

The collection of streamflow data over many years provides a data record which helps define the statistical properties and trends which are useful for studying future water resource uses. Generally, at least 10 years of data are needed at a site before any meaningful statistical and hydrologic properties can be determined. Additional years of data further reduce the uncertainty inherent in statistical analyses. The data is also used to derive regionalized equations for the determination of various flow statistics at ungaged sites. Formulas have been developed for mean annual and monthly flows, low-flows, and flood-frequency flows for application to ungaged watersheds throughout the State of Maine. These formulas and the data used in their derivation are utilized by various state and federal agencies, design engineers, and others to evaluate water resources in Maine.

Table 2 Significant Gaging Stations

Gage Number	Station Name	Drainage Area (mi^2)	Period of record	Comments (see below)
01041000	Kennebec River at Moosehead	1268	10/19 - 09/82	Inactive
01042500	Kennebec River at The Forks	1590	10/03 - now	FERC DCP
01043500	Dead River nr Dead River	516	10/39 - 09/82	Inactive
01045000	Dead River at The Forks	867	10/02 - 09/07 10/10 - 09/79	Inactive
01046000	Austin Stream at Bingham	90	10/31 - 09/69	Inactive
01046500	Kennebec River at Bingham	2715	10/07 - 09/09 10/30 - now	FERC
01047000	Carrabassett River nr North Anson [a]	353	10/02 - 04/07 08/25 - now	R, NWS, DCP
01048000	Sandy River nr Mercer	516	10/28 - 09/79 06/87 - now	R, NWS, DCP
01048500	Kennebec River at Waterville	4228	10/1893 - 09/35	Inactive
01049000	Sebasticook River nr Pittsfield [a]	572	11/28 - now	R, NWS, DCP
01049130	Johnson Brook at South Albion	2.9	05/80 - 09/91	Inactive
01049265	Kennebec River at North Sidney [a]	5403	10/78 - now	QW, NWS, T
01049300	N. Br. Tanning Brook nr Manchester	0.9	11/63 - 09/83	Inactive
01049373	Mill Stream at Winthrop	32.7	10/77 - 09/92	Inactive
01049500	Cobbosseecontee Stream at Gardner	217	10/1890 -9/64 10/76 - now	FERC
01049550	Togus Stream at Togus	23.7	10/81 - now	D,DCP

a = Station targeted for elimination

Comment Key

Inactive - Site discontinued
FERC - Federal Energy Regulatory Commission permit site
DCP - Satellite telemetry at site
R - Regional hydrology site
NWS - National Weather Service data site
QW - National Water Quality site
T - Telephone telemetry at site
D - Discharge permit site

Real-time stream flow data in the Kennebec Basin is retrieved daily by the NWS, Central Maine Power Company (CMPC), and the Kennebec Water Power Company. The NWS monitors the flows and models antecedent conditions in the basin so that their river-forecast model is calibrated. Utilities, such as CMPC and the Kennebec Water Power Company, monitor flows in the basin as part of their daily planning and managing of reservoir operations in the headwaters. Proper watershed management in the Kennebec River is necessary to make certain the requirements of the various water-users are met.

The collection of snow data at about 180 sites is coordinated on a state wide basis by the USGS office in Augusta. Information gathered by the various river basin managers, power utilities, and paper companies is combined with data from 75 sites in the USGS program to supply adequate coverage statewide. Figure 2 shows an example of a USGS snow survey report. Data is collected monthly in January and February, and then every two weeks until the snowpack is depleted. The progression of snow accumulation and ripening of the snowpack is evident from this data base, and the maps of water content are available for reservoir fill planning by river basin managers and for river forecasting by the NWS.

One of the uses of data collected in the Kennebec River Basin is to support NWS hydrologic modeling. The NWS models daily discharge, river stage, and monthly water supply for numerous locations within the basin. To support NWS hydrologic modeling efforts in the Kennebec River basin, streamflow data from six locations are collected. Table 3 summarizes real time hydrologic data collection in the Kennebec River basin by the NWS.

The upper portion of the main stem of the Kennebec River is monitored by the CMPC for flood control and hydroelectric purposes. The daily discharge data collected from Bingham is used by the NWS to monitor the upper reaches or headwaters of the basin. Discharge at Bingham is calculated based on the tailwater elevation below Wyman Dam. Since regulation of the Kennebec River above Wyman Dam tends to effect flood wave synchronization, this is an important data collection point. Discharge readings at Skowhegan are also provided to the NWS by the CMPC. Discharge at Skowhegan is calculated based on the tailwater elevation below Weston Dam.

Data collected at North Sidney is used by the NWS to monitor stages at Augusta near the Father Curran Bridge using a stage-stage relationship which correlates the observed stages at North Sidney with the stage downstream at Augusta. When the river stage at Augusta

Maine Cooperative Snow Survey Program

Water content in snowpack (in inches) – March 28 to March 31, 1994

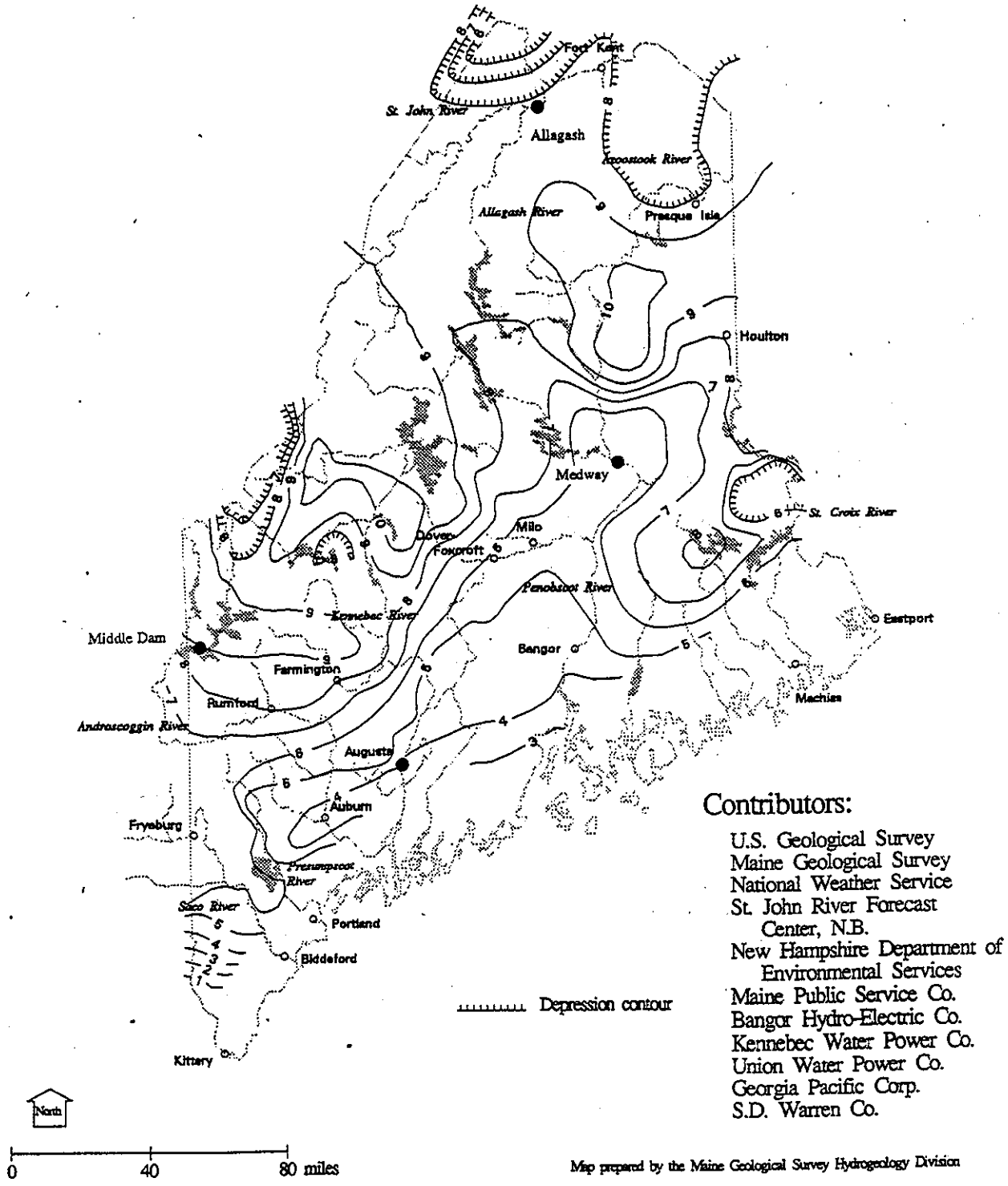

Figure 2 USGS Snow Survey Report

Table 3 Kennebec River Data Collection Summary

River Location	River Mile [1]	Drainage Area mi^2	Data Collected	Collection Frequency: Non flood periods	Collection Frequency: Flood periods	Agency
Kennebec @ Bingham	119	2,619	Discharge	2.	3.	CMPC
Kennebec @ Skowhegan	82	3,900	Discharge	2.	4.	CMPC
Kennebec @ No.Sidney	55	5,403	Stage	2.	4.	NWS
Carrabassett @ N. Anson	105	353	Stage	5.	5.	NWS
Sandy @ Mercer	102	516	Stage	5.	5.	NWS
Sebasticook @ Pittsfield	78	572	Stage	5.	5.	NWS

NOTES:
1. River mile from mouth of Kennebec River
2. Daily at 12:00 universal time code (UTC)
3. Every 6 hours
4. Instantaneous as needed
5. Every 4 hours

exceeds 10 feet, or at the request of the NWS, the Augusta Police take actual river stage measurements off the Father Curran Bridge using a wire weight gage.

Streamflow is monitored for three other sub-basins within the Kennebec River basin. Data from the Carabassett River at North Anson and the Sandy River at Mercer, along with other information, is used to model discharge at Skowhegan. Data collected from the Sebasticook River at Pittsfield and other locations is used to model river levels at North Sidney.

3.4 National Weather Service Hydrologic Forecasts

The primary mission of the NWS hydrologic program is to save lives and reduce property damage through the accurate and timely issuance of flood warnings and river forecasts. NWS River Forecast Centers (RFCs) are staffed with professional hydrologists who use computers to process and analyze data required to make river forecasts. During non-flood periods, RFC hydrologists make daily streamflow forecasts that are supplied to NWS Forecast Offices (NWSFO's) with public hydrologic service area (HSA) responsibility. The RFCs also produce long term flow forecasts for water management, provide guidance products for the flash flood program, and prepare seasonal water supply forecasts. Forecast procedures are developed for new locations and existing procedures updated to reflect physical changes to the rivers caused by structural changes, such as the addition of navigation dams and reservoirs.

Public hydrologic services are provided by NWSFOs with HSA responsibility. HSA responsibilities include: data acquisition management; public hydrologic forecasts dissemination; flood watch and river flood warning; forecasts and warnings dissemination; and, interaction with State and other Federal agencies with hydrologic or water resource missions.

3.5 Flood Damage Areas

The cities and towns described in this section were taken from the 1989 Corps Water Resources Study Reconnaissance Report prepared for the Kennebec River Basin. Because of the large number of cities and towns in the basin, only those with estimated losses in the 1987 flood of $500,000 or greater were selected for further evaluation. Nine locations were determined to be at high risk for flood damage in the Kennebec River basin based on this $500,000 criteria. The nine locations, listed in order of decreasing average annual loss from flooding (provided in parentheses) are:

1. **Gardiner/Randolph** ($535,800) - 56 commercial structures are prone to frequent flooding, as their elevations are 5 to 8 feet below the 100-year flood elevation. The Cobbosseecontee Stream flows through this area before joining the Kennebec. The lower section of Cobbosseeconte is subject to flood damage when the Kennebec is at high stages and backs up into this stream. Recurring losses are high even for the 10-year frequency flood at Gardiner.

2. **Augusta** ($209,400) - Most damages from flooding of the Kennebec River occur along the downtown commercial area along Water Street. Significant damages begin with the 50-year event.

3. **Winslow/Waterville** ($198,400) - Losses for this location become significant with the 50-year event, three properties account for the majority of damages along this reach of the Kennebec River.

4. **Farmington** ($125,400) - In this area, 28 of the 32 structures with flood loss potential have first floor elevations below the 100-year flood elevation of the Sandy River. This results in considerable recurring losses at the more frequent flood events.

5. **Hallowell** ($117,100) - Recurring losses become substantial at events approaching the 50-year flood from the Kennebec River. The 30 flood prone structures are retail establishments along the main street in Hallowell.

6. **Pittsfield** ($95,900) - Significant damage can occur with the 10-year flood on the Sebasticook River, as there is only a 2 foot difference between the 10-year and 100-year flood in the floodplain. Many of the structures in the floodplain are residential, with first floor elevations of up to two feet below the 100-year flood.

7. **Madison** ($93,400) - This area has only one flood prone location, the Madison Paper Industries buildings. A private system of dikes and walls provide protection up to a 50-year event on the Kennebec River.

8. **Skowhegan** ($69,400) - Most losses occur with the 100-year event on the Kennebec River. Two-thirds of the losses are within two industrial concerns and a hydroelectric plant.

9. **Fairfield** ($55,000) - Damages become significant with the 100-year event on the Kennebec River.

3.6 Gaps in Forecast Locations

Four of the 9 areas listed in the preceding section were determined to have inadequate NWS hydrologic services based on damages from a 50-year event of $1 million or greater,

or local requests to NWS for river forecast information. The damage areas that could use forecasts are Gardiner/Randolph, Winslow/Waterville, Hallowell and Farmington.

3.7 Kennebec River Damage Areas, Forecasts, and Warnings

Currently for the Kennebec River, the Northeast River Forecast Center (NERFC) in Taunton, Massachusetts, computes river stage forecasts every 6 hours for the Sandy River at Mercer, the Carrabassett River at North Anson, and the Sebasticook River at Pittsfield, and the Kennebec River at Skowhegan and North Sidney. NWSFO Portland, Maine has public HSA responsibility for the Kennebec River basin and receives daily river forecasts from the NERFC, using them to issue river flood warnings during flooding situations. During non-flood situations NWSFO Portland issues no forecasts to the public.

NWSFO Portland's public HSA responsibility includes issuing river flood warnings to the public for two locations in the Kennebec River basin, Skowhegan and Augusta when flooding is forecast or occurring. The flood warnings for Skowhegan are based on the actual NERFC forecasts. The flood warnings for Augusta are based on NERFC forecasts for North Sidney. The USGS has developed a stage-stage relationship between North Sidney and Augusta that allows NWSFO Portland to provide river flood forecasts for Augusta based on the NERFC North Sidney forecast.

A summary of damage areas and NWS daily forecast points and flood warning points for the Kennebec River Basin are shown in Table 4.

Table 4 Damage Areas versus NWS Forecasts and Warnings

Damage Areas	Annual Damage ($K)	Daily Forecasts Provided?	Flood Warnings Provided?
Gardner/ Randolph	535.8	No	No
Augusta	209.4	Yes	Yes
Winslow/ Waterville	198.4	No	No
Farmington	125.4	No	No
Hallowell	117.7	No	No
Pittsfield	95.9	Yes	No
Madison	93.4	No	No
Skowhegan	69.4	Yes	Yes
Fairfield	55.0	No	No

4.0 NATIONAL WEATHER SERVICE HYDROLOGIC FORECAST SERVICES

On a daily basis the NERFC provides the NWSFO Portland with daily river forecasts. Based on the forecasts provided by the NERFC and the potential for flooding, NWSFO Portland issues a number of public hydrologic products including flood potential statements and flood watches and river flood warnings.

While rainfall is the predominant factor affecting flooding in Maine, runoff from snowmelt contributes to flood flows in the spring. The flood potential statement assesses the long-term potential for flooding based on snow-pack water equivalent measurements and the hydrologic state of the basin. A flood watch is the first level of alert for the public and emergency managers. It is issued by the NWSFO Portland if, based on the results of meteorologic observations, 5-day precipitation forecasts, snow pack conditions and present river levels, flooding is possible. Issuing a flood watch does not mean flooding is imminent, but is possible.

Under a flood watch, the NERFC makes preparations to develop flood forecasts on a more frequent basis if the weather conditions develop as forecasted. The NWSFO Portland coordinates with the USGS and dam operators to obtain current and planned reservoir operations schedules. The NWSFO Portland sends the flood watch to the appropriate State officials, media, and disseminates it over the NOAA Weather Radio.

If observed or forecasted rainfalls and river levels indicate flooding is likely or imminent, NWSFO Portland issues river flood warnings for specific river locations. The flood warning is broadcast over the NOAA Weather Radio as well as the National Warning System (NAWAS). An example of a river flood warning is presented in Figure 3.

BULLETIN
RIVER FLOOD WARNING FOR MAINE
NATIONAL WEATHER SERVICE PORTLAND MAINE
930 AM EDT SUN APRIL 11 1993

... A FLOOD WARNING HAS BEEN ISSUED FOR THE KENNEBEC RIVER

THE KENNEBEC RIVER AT SKOWHEGAN HAD A FLOW OF 20930 CUBIC FEET PER SECOND AT 9 AM AND WAS INCREASING RAPIDLY. FLOOD FLOW IS 35000 CFS. THE RIVER IS EXPECTED TO CREST BETWEEN 50000 AND 55000 CFS BY 1 AM MONDAY.

THE KENNEBEC RIVER AT AUGUSTA WAS AT 8.49 FEET AND RISING AT 9 AM. FLOOD STAGE IS 13 FEET. THE RIVER IS EXPECTED TO CREST BETWEEN 14 AND 15 FEET BY 7 AM MONDAY.

Figure 3 Example River Flood Warning

4.1 River Forecast Modeling

Computer-based river models for the Kennebec River basin have been developed by the NERFC to forecast river stages at select locations. These models use data supplied from a variety of sources including the USGS, hydroelectric utilities, and paper manufacturers. NWSFO Portland uses the forecasts from the NERFC to issue flood watches and river flood warnings for the Kennebec River Basin.

4.2 River Forecast Input Variables

The hydrologic models used by the NERFC calculate the amount of rainfall and melting snow that will reach a river as runoff, then estimate the time it will take the runoff to reach a forecast point. Factors affecting the amount of runoff that contribute to river flow include rainfall, basin soil type, soil moisture at the time of rainfall, vegetation and season, topography, state of the ground (frozen/non-frozen), and snow pack water-equivalent. Many of these factors are difficult to measure directly and are estimated. Fortunately, rainfall and the current river stage/discharge, the most important inputs into the river forecast models, can be measured directly.

4.3 River Stage Forecasts

Several steps are involved in making river stage forecasts. The hydrologic models used by the NERFC divide the Kennebec River basin into five sub-basins. Table 5 lists the sub-basins used to compute runoff for forecast points, hydrometeorological data inputs, and sub-basins used for routing calculations. For the individual sub-basins, basin average precipitation is computed from all available rain gage data. Using formulas developed for each sub-basin and basin average rainfall, the computed rainfall and snow melt are converted to a forecast of runoff. The runoff is converted to a forecast of river flow. River flow is routed downstream on the river and combined at specific NWS flood forecast locations.

Finally, the flow is converted to a stage by using a rating curve, which is a relationship of river stage versus river flow. The forecasted time and height of the river stage is issued in NWS river flood warnings.

Table 5 Number of Model Input Sensors and Routing Sub-Basins

Sub Basin	Precip	Temp	Discharge	Routing Basins
Carrabassett R. @ North Anson	6	4	1	local
Sandy River nr. Mercer	6	6	1	local
Kennebec R. at Skowhegan	4	2	1	North Anson Mercer Bingham
Sebasticook R. nr. Pittsfield	6	4	1	local
Kennebec R at North Sidney	6	4	1	Skowhegan Pittsfield

4.4 Interactive Portion

The interactive portion of the river forecast model allows the hydrologist to adjust the amount or timing of the calculated runoff. Adjustments are made by matching the calculated to the observed runoff hydrographs (relationship of flow at a location to time). These adjustments are based on actual river gage readings. The forecaster's interactions are needed because of the inaccuracies in measuring parameters, and because runoff and model assumptions are not always met. During flood events, real time stream gage data are used to update the hydrologic models continuously. The gage readings are used by the hydrologist to calibrate and adjust the forecasts based on model output.

Usually the spring snowmelt runoff events require more complex calibration because they include runoff from rain, snowmelt and ice jam flooding. These events require a large amount of adjustments to the model forecasts. The adjustments are not possible without snow water equivalent estimates and river gage data.

4.5 Future Operations

The NWS is presently modernizing its equipment and operations, which will result in improved data collection, processing and forecast techniques used by NERFC and NWSFO Portland in the Kennebec River Basin. A highly visible sign of the NWS Modernization and Associated Restructuring is the new Weather Service Radar-1988, Doppler (WSR-88D). The WSR-88D combines recent advances in radar and computer technology. The WSR-88D data will be used to more precisely define the distribution and timing of precipitation over the Kennebec River basin. The WSR-88D provides graphical one-hour, three hour, and storm total precipitation displays. These products use Cartesian grid with a 2-kilometer x 2-kilometer resolution.

To take advantage of the more advanced computer technology, the NERFC is updating the computer model used to forecast flows for the Kennebec River and its entire service area. The model is part of the National Weather Service River Forecast System (NWSRFS), which allows for more detail in defining the Kennebec basin, and will more accurately reflect the physical processes which occur in the basin. The NWSRFS will improve the forecasts and provide the ability to make longer term flow forecasts. One of the features of the NWSRFS is the ability to simulate river flows over long periods of time. Complementing the enhancements provided by the NERFC, a Hydrometeorological Forecast System for the NWSFO Portland will be developed. NWS planning documents have shown (NWS, 1990) that the coupling of hydrologic and meteorologic operations and science can produce an increase in forecast lead time of up to 6 hours thereby likely providing a reduction in flood damages. In addition, the enhanced Hydrometeorological Forecast System will improve the accuracy of river stage forecasts and lead to more objective techniques in the production of NWS River Flood and Flash Flood Watches and Warnings.

5.0 EFFECTS OF LOSS OF DATA ON RIVER FORECASTS

The effect of the elimination of the snow survey program and the loss of three of the four gages used to forecast flood flows in the Kennebec River is described in this section. One of the primary objectives of this section is to determine, based on available information, if the elimination of the snow survey program and the cooperative river gage program would require the NWS to fully implement their policy to only issue categorical river flood warnings (minor/moderate/major), or to determine if there is enough information available to provide some (reduced) level of river flood forecasts services to the Kennebec River Basin. Appendix 2 reviews NWS policy concerning the elimination of gage information.

5.1 Elimination of Snow Survey Program

The elimination of the snow survey program would hamper the NWS's ability to determine the potential for spring flooding. Each year, starting in late winter, NWSFO Portland issues several flood potential statements. The likelihood of spring flooding is determined by comparing the present snow water-equivalent on the ground, soil moisture content, and prevailing temperatures with similar data from previous years. The coordinated snow survey is a major factor used in the analysis of the spring flood potential for the Kennebec River basin.

Elimination of the snow survey program would also limit the validation of the snow model component of the river forecast system. Periodically during the snow season, the snow model parameters are adjusted to accurately reflect the current snow condition. Without the detailed snow survey information, parameter calibration would be more difficult. This could lead to inaccurate forecasts during the time of year with the greatest flood threat.

An example of the value of the snow survey program was observed during the April 1987 floods in the Kennebec River basin. During the 1987 event, the contribution of snowmelt to the record flood was large, as much as four inches of runoff (Budd, 1987) out of the five inches runoff measured at North Sidney. That is the reason the snow survey was reinstated after the 1987 flood. The prior record flood (1936) was also a combination of snowmelt and rain.

5.2 Elimination of Stream Gages

Previous studies were reviewed and past events modelled to determine what impact the elimination of the three real time gage readings used by NWS forecasters would have on the timeliness and accuracy of river flood warnings.

5.3 Previous Studies

The COE (1990) investigated floods between 1973 through 1987 and concluded that on average, 15 percent of the peak flow at North Sidney was accounted by the Carabassett River at North Anson and 10 percent by the Sebasticook River at Pittsfield. It is obvious from this fact alone that forecast accuracy at North Sidney would be adversely impacted if these gages could no longer be used in forecast preparation. However, further analysis occurred in an attempt to quantify the impact at North Sidney/Augusta due to removal of these gages.

5.4 NERFC River Forecast Model Analysis

The NERFC's River Forecast Model (RFM) was used to evaluate what effect gage elimination could potentially have on the NWS's ability to forecast flood events on the Kennebec River. The RFM is an event driven model, which can effectively simulate gage outages for specific events, and provide insight into the effect of gage outages on river forecast accuracy.

Three events were simulated to illustrate the impact of real time missing river gage data. Hydrologic situations for the three events were recreated and then modeled with and without stream gage readings. These model runs objectively evaluated the impacts of the loss of gage data on the RFM's performance for each event. All of the RFM model runs were calibrated because they were initiated from measured hydrologic conditions. Because the RFM is an event driven model, it illustrates the impacts of gage losses during single events only.

The three events representing different categories of flooding were chosen based on magnitude. They range from minor to major flood events. The April 1993 flood was considered a minor flood; the May 1989 event was a moderate flood; and the flood of April 1987 was the flood of record for many locations along the Kennebec River. The hydrologic situation and modeling details are presented in Appendix 1.0.

5.5 Results

Based on the limited study, it is clear that the forecast lead time is significantly effected for river forecasts in the lower Kennebec basin at North Sidney/Augusta. Unfortunately the model simulations for the gage outages did not optimally illustrate the long term effect of the loss of the three stream gages used by NWS in the Kennebec River Basin. To effectively simulate this, a continuous hydrologic model would have to be used. In the future, the NERFC will use a continuous river forecast model that will have some degree of model skill based on calibration that can be done with historic data.

Without stream gage data from North Anson, Pittsfield and North Sidney, the NWS could not model river levels on the Carrabassett River at North Anson or on the Sebasticook River at Pittsfield with any degree of confidence. For these locations, river gages provide the only measurement of discharge for these sub-basins in the Kennebec River Basin. Currently, there are no flood warnings issued for these locations. In addition to impacting the forecasts at other locations, the removal of these gages would foreclose any future opportunities to issue specific stage and time to crest forecasts for these locations. The type of flood warnings that could be issued for these locations would be generic in nature, merely describing the expected magnitude of flooding (minor/moderate/ major). Appendix 2.0 describes the NWS Eastern Region Policy concerning the issuance of forecasts for non gaged locations.

Three river forecast simulations were done to provided a first look at quantifying the effect of gage closures on the forecasts on the Kennebec River at Skowhegan, and further downstream at North Sidney/Augusta. Three flood events on the Kennebec River were used to determine the short term effect of elimination of stream gage operation. Forecasts were recreated by using information supplied by gages not affected by potential gage closures. All the gage information, including those that may be abolished, were used to initiate the model runs. Comparisons between the forecasts and observed values provide some insight to the importance of data from the threatened gages for river flood forecasting.

Forecast lead time to flood stage is an important factor for the users of river flood forecasts. It allows users to respond with emergency actions and reduce the cost of flood damages (see Section 6.0). For the two model runs that reached flood stage (April 1987 and May 1989), the travel time of the flood wave was calculated to the nearest 6 hour

interval. Using all of the gages, the maximum forecast lead time to flood stage for the Kennebec River at Skowhegan was 24 hrs and for Augusta was 30 hours. These lead times are based on real time collection of hydrometeorological model parameters including precipitation and streamflow.

If the three gages were eliminated, the forecast lead time for Skowhegan would not be severely effected because timely and accurate river flow information is provided by the CMPC from Bingham (Wyman Dam). On the other hand, the elimination of the three gages significantly effect the timing of the flood forecast at Augusta. If those gages were eliminated the North Sidney/Augusta forecast would only be based on discharge information from Wyman Dam at Bingham and Weston Dam at Skowhegan. This would result in an 18 hour reduction in lead time for Augusta. The lead time would be reduced from 24 hours to 6 hours.

The forecast and percent error for both Skowhegan and North Sidney/Augusta with and without the use of the three stream gages threatened for closure (North Anson, Pittsfield, and North Sidney) are illustrated in Table 6 and Table 7.

The elimination of the North Anson gage would reduce the forecast ability at North Anson. Downstream at Skowhegan, the flows from the Carrabassett River are less significant, and the forecast flow would be adjusted at Skowhegan to reflect the observed flow. Further downstream at North Sidney/Augusta, the flow from the Carrabassett becomes even less significant. The interactive aspect of the RFM also allows for adjustments of flow at Skowhegan, thereby reducing the errors that may be present due to the missing North Anson data. A review of the analysis in Appendix 1 shows that, for the three events modelled, the accuracy of the flood flow forecast improved an average of two percent at Skowhegan using the North Anson gage. The use of North Anson, Pittsfield and North Sidney gages together improved the peak flow forecast accuracy at North Sidney/Augusta by an average of 10 percent for the three events modelled.

Table 6 Skowhegan Forecast Percent Error Compared to Observed

Skowhegan	With all Gages	Without all Gages	Difference
April 1993	0.9	1.2	0.3
May 1989	1.0	4.2	3.2
April 1987	14.3	17.8	3.5

Table 7 North Sidney/Augusta Forecast Percent Error Compared to Observed

North Sidney/ Augusta	With all Gages	Without all Gages	Difference
April 1993	10.5	24.6	14.1
May 1989	4.4	9.6	5.2
April 1987	2.6	11.7	9.1

6.0 USES OF FLOOD WARNING INFORMATION FOR FLOOD DAMAGE REDUCTION AND FLOODPLAIN EVACUATION

6.1 Purpose of Flood Warning

The purpose of flood warning is to provide floodplain occupants, business owners, emergency management officials and others with adequate warning to take actions prior to the peak of the flood to evacuate the floodplain and mitigate property damage. Two types of actions may be taken in response to a flood warning: 1. evacuation of the floodplain to reduce the risk of injury to occupants, and; 2. flood damage reduction activities. Flood damage reduction may occur when floodplain residents or business owners move items such as cars and building contents out of the path of the expected floodwaters, or implement floodproofing measures, such as the placement of window or door seals to keep floodwaters out of the building. Emergency management officials may also use the warnings to close roads and bridges to prevent access to streets susceptible to flooding.

A flood warning and response plan clearly outlines the actions that should be undertaken under various potential flood scenarios. Scenarios should include the various levels of forecasted flooding, the time available to respond, the time of day (especially day versus night) and day of week (especially weekday versus weekend) of flooding. The preparation of a flood warning and response plan well in advance of a flood's occurrence enables the maximum benefits from flood warning. The resources likely to be available to mitigate flooding under the various scenarios must be anticipated, and preparations to address any identified shortcomings should be made. A flood warning and response plan may also provide intangible benefits such as providing a greater degree of security to those living in the floodplain, and a better educated public that may respond more effectively.

6.2 Flood Warning and Response Systems

All successful flood warning and response systems include four components: 1. flood threat recognition; 2. flood forecasting and warning message creation; 3. warning message dissemination; 4. flood warning response.

6.2.1 Flood threat recognition:

The flood threat recognition component is the mechanism through which the appropriate officials are initially made aware of the potential threat of flooding affecting their area.

6.2.2 Flood Forecasting and Warning Message Creation:

The flood forecasting and warning message creation component includes the analysis of data to facilitate the preparation of a flood forecast(s) for the covered area. The nature and specificity of the forecast depends upon several factors including the number and location of gages available to prepare forecasts. Prior studies indicate that a response to a warning is more likely to occur if flood warnings are specific, rather than general. It is likewise recognized that longer lead times enable a maximization in reducing property damages. The warning messages created to communicate the forecast must be carefully tailored to the intended audience and should provide explicit instruction on actions to be taken.

6.2.3 Warning Message Dissemination:

The warning message dissemination component is the mechanism of transmitting the warning message to the responsible public officials and the general public, particularly those in the floodplain. Methods of message dissemination may include the use of telephones, police radios, sirens, radio and television broadcasts, and house-to-house notification. The message dissemination procedure may vary with the time of the day, day of the week, forecast lead time, and other factors.

6.2.4 Flood Warning Response:

The response component includes all actions taken by the public and private sector to minimize flood related damages. Considerable attention must be given to this aspect since most flood reduction benefits are dependent on the predetermined response to a flood threat. Public officials may use a warning to block off low-lying roads, assist those with special cases (e.g. the elderly, or hospital occupants), ready temporary shelters, or initiate floodproofing measures. The public may respond to the warning by evacuating the floodplain, moving cars and building contents out of the expected path of the floodwaters, or implementing floodproofing measures.

6.3 Flood Warning and Response in the Kennebec River Basin

6.3.1 Introduction

The Maine Emergency Management Agency (MEMA) works closely with the National Weather Service (NWS), particularly during late winter and spring, when the flood threat is the greatest. Communication channels are periodically tested between the pertinent Federal, state, and local officials to insure their successful operation during an emergency. For the Kennebec River basin, flood threat recognition is initially provided when the NWS in Portland, Maine notifies the MEMA and other appropriate state officials, radio and television stations, and other media of a potential flooding situation. A flood watch is the first level of alert. The watch is broadcast over NOAA Weather Radio, and the media advise the public to tune in to radio and television stations for updates. The watch is also broadcast over the National Warning System (NAWAS) which is monitored by many levels of federal, state and local government. The Maine State Police headquarters is the primary point of contact, with MEMA being the alternate point of contact, although all of the parties receive the flood watch notice through NAWAS simultaneously. MEMA then notifies county emergency management agencies (EMAs) and the Emergency Response Team (ERT), composed primarily of several state agencies that pool resources and information during emergencies.

If the flood potential increases, NWS in Portland issues a flood warning, broadcasting the warning over the NAWAS, and through other means. The State Police repeat the message on their statewide radio system, thereby getting the message to all State troopers, local police and fire departments. County sheriffs notify all county EMAs, who relay the message to local towns. A detailed news release is then issued by the Joint Information Center, MEMA's disaster information center. For more information on emergency response measures taken by state and county officials, the reader is referred to MEMA's 1993 report: "When the Rivers Rise; Flood Awareness for Maine Public Oficials". The 6-hour forecasts prepared by NWS are critical to MEMA and county and local EMAs for directing emergency operations, and for decisions to issue evacuation orders for floodplain occupants. The responsibility for flood forecasting and warning message creation is divided, with NWS preparing numeric (i.e. specific) forecasts for Skowhegan and Augusta, and MEMA preparing explicit instructions to the targetted audience.

It is the responsibility of local officials to alert floodplain residents, evacuating them, providing shelter for those who need it, and providing other services as needed. Higher levels of government are brought in if the local situation overwhelms local capabilities.

6.3.2 The April 1987 Flood

Estimates of damages sustained in the Kennebec River basin resulting from the April 1987 flood (flood of record) were $34 million (US Army Corps of Engineers, 1989). Besides shortcomings in the warning system, other factors contributing to the large amount of damages included a lack of preparedness on the part of the floodplain occupants, and the failure of people to take seriously warnings that were issued (Ref: U. Maine's 1987 special report).

6.3.3 Flood Warning and Response After the 1987 Flood

Subsequent to the 1987 flood, snow surveys were re-instituted, the state has improved the communication process with NWS and others. The Maine Emergency Management Agency has developed a "staged" plan of readiness to respond to NWS flood warnings/forecasts, with activation and readiness increasing (staged) as NWS forecasts proceed from flood watch to flood warning to the issuance of numeric flood stage forecasts.

In response to the recognition that a large portion of the flood damages received in 1987 were preventable, Somerset County is currently increasing its flood preparedness. Somerset County encompasses the mainstem Kennebec River basin from upstream of Great Moose Lake to the Town of Fairfield. The County recognized that the most significant problem with the warning process in place during the 1987 flood was the lack of understandable, explicit instruction associated with the warnings of flooding it received. Until 1987, there was an overall lack of awareness of the extent of the flood zone by community officials, and no way of associating a stage forecast at the Skowhegan gage with the expected flood depth at other locations.

In response to the identified deficiencies, Somerset County has surveyed 29 control points along the Kennebec River from Bingham to Fairfield. This effort has been funded by a Hazard Mitigation Assistance Grant from the Federal Emergency Management Agency (FEMA). With local community input, staff gages are being deployed and surveyed using a

series of control points established as part of this project. The purpose of the staff gages is to translate the stage forecast at the Skowhegan gage to the expected flood depth at other locations. The County is now in the process of developing these relationships. In this way, communities in the county will know what the forecast at Skowhegan is expected to mean in their communities. Training was provided to community fire, police, and public works departments in reading both the gages and FEMA's Flood Insurance Rate Maps.

Somerset County is hoping that implementation of the expanded flood warning and response system will enable communities to apply for a reduction in flood insurance rates for its citizens. The reduction in rates would be associated with credits that towns may receive under FEMA's Community Rating System (CRS). The CRS was developed by FEMA to provide the opportunity for communities who support a local program which exceeds minimum requirements of the National Flood Insurance Program to obtain reduced flood insurance premium rates for their citizens. The expanded flood warning and response system is critically dependent upon NWS providing a specific stage forecast for Skowhegan, and not merely a categorical (generic) forecast. In addition, sufficient advance warning is needed to insure successful use of the information.

6.4 Flood Warning and Response in the Kennebec River Basin With a Reduced Gage Network

During the course of the preparation of this report, the State of Maine requested that the Corps estimate the increased damages caused by the reduced level of flood forecast services caused by the loss of the gages presently available for forecasting in the Kennebec River basin. Because a detailed economic analysis was beyond the scope of this project, a simplified cost savings approximation technique was used to estimate the increase in damages due to a reduced gage network. The only areas examined were Augusta and Hallowell.

The impact to the flood forecasts provided by NWS for North Sidney/Augusta has been determined to be a reduction in the accuracy of the stage forecast, along with a decrease in warning time from 24 hours (at present) down to only 6 hours. No attempt is made in this report to estimate the monetary damages associated with a reduced forecast accuracy level.

A decrease in warning time of an impending flood leads to increased flood damages since residents and business owners have less time to move vehicles and building contents out of

the path of the expected floodwaters and less time to employ other flood damage-reduction measures. The general relationship of warning time to the reduction in total flood damage is shown on Figure 4. Although not accurate for all locations, it does indicate the general relationship of warning time and flood damages.

The relationship graphically illustrated in Figure 4 was based on a study by Harold Day of Carnegie Mellon University of residential flood damages along several river reaches in Pennsylvania and New York. The relationship, referred to as the "Day Curve", overestimates the benefits of flood warning due to its being based upon 100 percent of the floodplain occupants responding to the warning. However, the Day Curve does not include damage reduction by moving cars out of the path of the forecasted floodwaters, an important response activity that can significantly reduce flood damages. It should be also noted that damage reduction is likely greater for commercial and industrial properties than for residential properties because they typically store a higher number of stock and contents on the lower floors. The relationship shown by the curve is, however, used below without modification in order to provide the ballpark estimate of increased flood damages with reduced warning time.

For purposes of developing an estimate for the Augusta/Hallowell area, it is assumed that warning time is reduced by 18 hours (from 24 hours with all gages in place, to only 6 hours with the reduced gage network), and that instantaneous dissemination of warning from NWS to local residents occurs.

Examination of the Day Curve indicates that total flood damages are reduced by 29 percent with 24 hours of advance warning. Total flood damages may be reduced by 14 percent with 6 hours of warning. The values listed in the "24 hrs warning" column of Table 8 are the average annual damages as reported in the Army Corps of Engineers 1989 Water Resources Study of the Kennebec River basin. The assumption is that the two communities generally receive 24 hours of advance flood warning prior to the peak of damage-causing floods. Applying the percent damage reduction values to Augusta and to Hallowell, both areas dependent upon the forecast for North Sidney/Augusta, provides the values listed in Table 8.

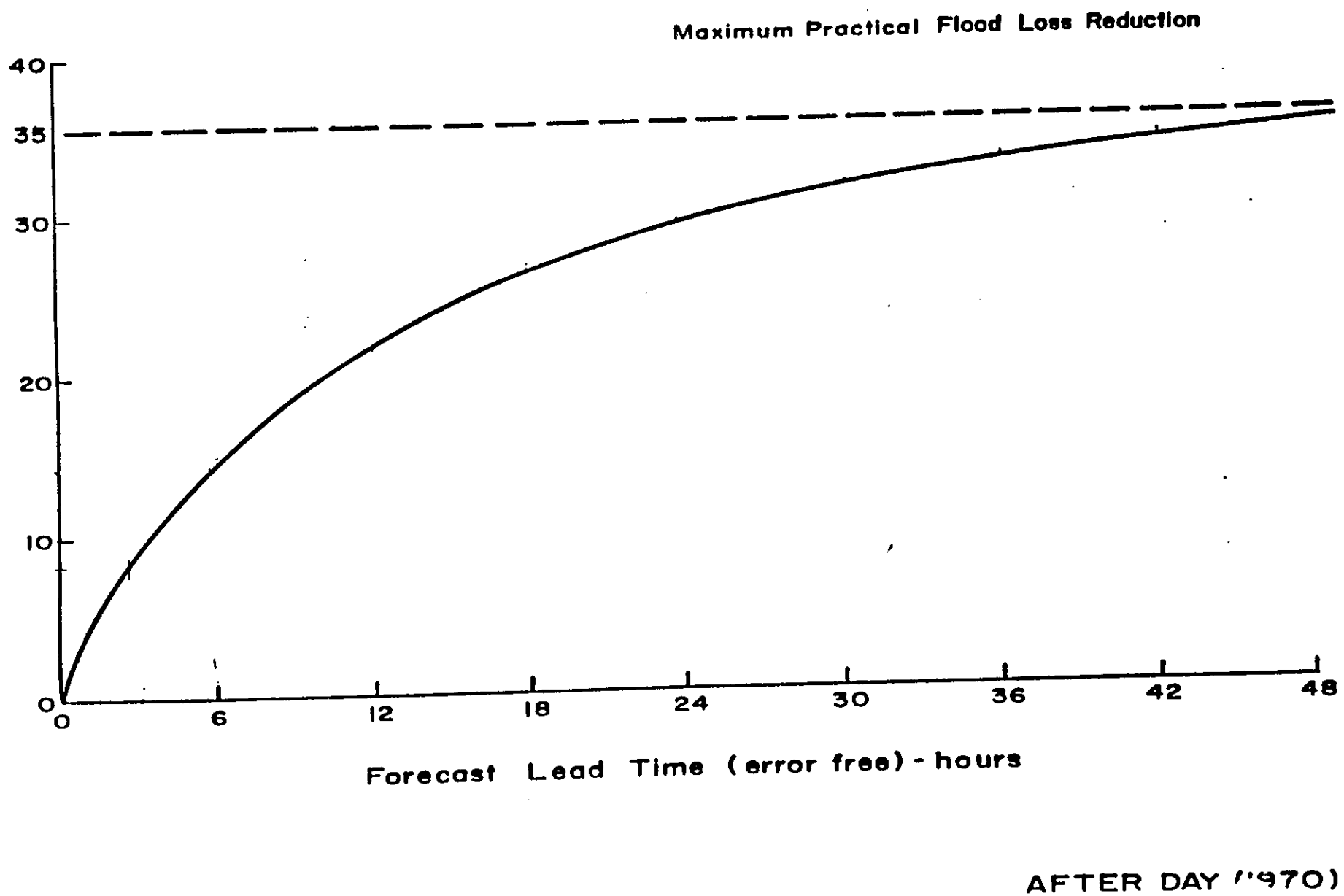

Figure 4 - Reduction in Total Flood Damages Versus Warning Time

Table 8 - Average annual flood damages at Augusta and Hallowell versus Warning Time

Community	no warning	6 hrs warning	24 hrs warning
Augusta	$294,900	$253,600	$209,400
Hallowell	$164,800	$141,700	$117,000

An examination of these results shows that average annual damages increase by $44,200 at Augusta and by $24,700 at Hallowell with a reduction in lead time from 24 hours to only 6 hours at North Sidney/Augusta. Impacts in other locations in the basin may be expected to be similar at all locations using the NWS forecast for North Sidney/Augusta. It should be noted that the reduction in lead time may lead to evacuation-related problems. In addition, MEMA and others may be forced to mobilize unnecessarily in anticipation of forecasted flooding.

No attempt is made in this report to extrapolate the increase in flood damages at other locations due to reduced warning time and/or a decrease in forecast accuracy. The increase in damages basin-wide due to the reduced gage network may be several times that estimated above for only Augusta and Hallowell.

7.0 CONCLUSIONS

This limited study illustrates the impacts of losing data from the three gages in the Kennebec River basin contemplated for closure, as well as the cessation of the collection of snow survey data. The study found one impact to flood forecasting to be a reduction in the ability of the NWS to accurately forecast flows for North Sidney/Augusta on the main stem of the Kennebec River, and for two of its major sub-basins: the Sebasticook River near Pittsfield and the Carrabassett River at North Anson. Although flood forecasts are not issued for the sub-basins, forecasts for the sub-basins are used in the preparation of forecasts for the two Kennebec River basin forecast points: Kennebec River at North Sidney/Augusta and Kennebec River at Skowhegan.

The most significant impact of the gage closures was found to be a great reduction in flood warning lead time at Augusta, a major damage area with $209K in average annual damages. If the gages are closed, and snow survey data collection ceases, flows at Augusta would be modeled based only on data collected at Skowhegan, supplemented by manual observations taken at the Father Curran Bridge at Augusta. Although the data would provide the minimum information to provide flood forecasts for Augusta, the forecasts would provide little valuable information for flood response because of the inadequate accuracy and lead time. Average annual flood-related damages in the Cities of Augusta and Hallowell would be expected to increase by roughly $44,000 and $25,000, respectively, primarily because of reduced warning lead time. Damages during a particular flood could be expected to be several times the average annual damages. In a simulation of the 1987 flood, the reduced number of gages was found to result in errors of almost four feet in flood stage (over 41,000 cfs in flood flow), and a loss in lead time of 26 hours (National Weather Service, 1995).

The impact on forecast accuracy and warning lead time would not be very significant at Skowhegan, however, since there is enough hydrologic data collected from the CMPC to provide specific river forecasts at that location.

The review of NWS operations revealed that if the current river gage network is kept intact, river flood forecasts and warnings can be issued for the Sebasticook River near Pittsfield. Since the NERFC issues a daily forecast internally for routing purposes, and Pittsfield has been identified as a flood damage area, the NWS should determine flood stage and investigate issuing river flood warnings to reduce flood damages at Pittsfield. There is likely to be minimal additional cost to issue these forecasts.

This study also determined that there is a need for additional flood forecast points in the Kennebec River basin. The NWS should investigate establishing hydrologic models for the following locations: Gardner/Randolph, Waterville/Winslow, Farmington, and Hallowell. The NWS notes also that it receives many calls from town officials and property owners along the Sandy River in Farmington for flood forecast information. However, without a river gage at Farmington, only categorical forecasts (minor, moderate, or major) can be provided.

APPENDIX 1.0 MODEL RUNS

April 1993 Event

The April 1993 flood was a result of moderate rains on saturated soils. In the beginning of the month, there was a significant snow pack. On April 3rd, the NWS's Cooperative observer at Phillips, Maine recorded 39 inches of snow on the ground. Phillips is located in the upper reaches of the Sandy River. In contrast, Augusta only had 5 inches on the ground for the same date. Most of the snow melted by April 15, and only traces were reported throughout the Kennebec basin on April 22.

On April 22, the rivers and streams in the basin were running higher than normal as a result of rain earlier in the week and snow melt. The rain began in the early afternoon, on April 22,and continued through the morning of the 23rd. Rainfall totals ranged between 0.20 inches at Bingham to 1.40 inches at Augusta. Rivers rose one to four feet resulting in minor flooding.

Table A1 illustrates the changes in the river forecasts obtained by using the gages at North Anson, Pittsfield and North Sidney. The forecast points are listed with their flood stages; observed crests; and forecast crests obtained with and without adjustments. The column labeled "None" contains the forecast crests calculated without gage information from these sites. Values in this column for North Anson and Pittsfield are unadjusted; for Mercer and Skowhegan, values are adjusted using their respective observed stages; at North Sidney the forecast benefitted from adjustment upstream at Skowhegan and Mercer. The column labeled "Forecast using North Anson" contains forecast crests at locations at or downstream from North Anson which are affected by adjustments made at North Anson. The last two columns are similar to the North Anson adjusted forecasts, and are for locations at or downstream from Pittsfield and North Sidney. These columns contain the cumulative effects of using all upstream adjustments.

Inspection of Table A1, reveals that at the Kennebec River at North Sidney, use of the North Sidney gage improved the forecast stage by 7200 cfs. At the same location, there were some added benefits from the North Anson and Pittsfield gage information. The use of the North Anson gage increased time of the crest at Skowhegan by six hours, resulting in a match between the forecast and observed crest times. Gage information from all sites was used to develop the initial conditions for the model runs. Therefore, the results reflect some use of the gages.

Table A1 Forecast crests for April 1993

Forecast Location	Flood Stage		Observed Crest		Forecast values using indicated gages							
					None		North Anson		North Anson Pittsfield		North Anson Pittsfield North Sidney	
	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft
Carrabassett River near North Anson	n/a	n/a	7,240	9.7	6,840	9.4	8,290	10.3				
Sandy River near Mercer	n/a	n/a	8,490	8.4	9,380	8.7						
Kennebec River at Skowhegan	35,000	--	32,900		32,500		33,200					
Sebasticook River near Pittsfield	n/a	n/a	6,030	8.1	5,500	7.7			5,630	7.8		
Kennebec River at North Sidney	54,400	18.0	54,400	18.0	41,000	15.6	41,500	15.7	41,500	15.7	48,700	7.1

May 1989 Event

The May flood event was a result of widespread heavy rains on already wet soils. May, 1989 was one of the wettest on record for the entire state of Maine. In the Kennebec Basin, the Farmington observer measured 9.91 inches for the month. Rainfall over the basin, for the first ten days of May, ranged from 2.95 inches at Phillips to 4.26 inches at Augusta.

The rainfall for this event began during the early morning hours of May 11 and continued through the morning of May 13. Rainfall totals for this event ranged between 2.71 in Harmony, located in the upper reaches of the Sebasticook, to 4.63 inches in Farmington, in the Sandy River Basin. River levels rose to cause moderate flooding on the Kennebec.

In Table A2, the results of the forecast runs for the May 11 event are listed. Inspection of the table reveals that the use of the North Anson gage slightly improved the forecast at both Skowhegan and North Sidney. Use of the Pittsfield gage slightly improved the forecast at North Sidney. Surprisingly, the information from the North Sidney gage did not improve the crest forecast. Before using data from the North Sidney gage, the crest was about 3000 cubic feet per second (cfs) too low; with the North Sidney data, the crest forecast was 3000 cfs too high. Adjustments with the North Anson gage delayed the timing of the crest by 6 hours at Skowhegan, resulting in a match in time of the forecast and observed crests at Skowhegan.

Table A2 Forecast crests for May 1989

Forecast Location	Flood Stage		Observed Crest		Forecast values using indicated gages							
					None		North Anson		North Anson Pittsfield		North Anson Pittsfield North Sidney	
	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft
Carrabassett River near North Anson	n/a	n/a	13,300	13.1	6,840	9.4	11,980	12.4				
Sandy River near Mercer	n/a	n/a	25,300	13.7	23,660	13.1						
Kennebec River at Skowhegan	35,000	--	65,000		62,300		65,700					
Sebasticook River near Pittsfield	n/a	n/a	5,930	8.0	4,840	7.0			4,410	6.5		
Kennebec River at North Sidney	54,400	18.0	75,000	21.1	67,800	20.2	71,300	20.6	72,020	20.7	78,300	21.6

April 1987 Event

This flood event was a result of large volume rains accompanied by snow melt. The flood producing rains started during the morning of March 31 and lasted through the early morning of April 1. At 7 am, on April 1, the 24 hour precipitation totals ranged from 3.03 inches at Skowhegan to 4.91 inches at Bingham. This was a major flood event on the Kennebec River and its tributaries.

In Table A3, the recreated flood forecasts are listed. It should be noted that the flow at Skowhegan was estimated, and appears to be too high. The use of the North Anson gage improved the forecast at both Skowhegan and North Sidney. The Pittsfield gage data helped improve the flow forecast at North Sidney. A major improvement in the forecast at North Sidney was made with the use of the North Sidney gage.

Table A3 Forecast crests for April 1987

Forecast Location	Flood Stage		Observed Crest		Forecast values using indicated gages							
					None		North Anson		North Anson Pittsfield		North Anson Pittsfield North Sidney	
	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft	Discharge cfs	Stage ft
Carrabassett River near North Anson			50,700	26.7	29,600	20.1	50,500	26.6				
Sandy River near Mercer[a]			51,100	19.2	no gage	no gage	no gage	no gage	no gage	no gage	no gage	no gage
Kennebec River at Skowhegan	35,000		240,000[b]		197,400		205,700	--				
Sebasticook River near Pittsfield			17,600[c]	15.5	6,820	8.7	n/a	n/a	9,640	10.7		
Kennebec River at North Sidney	54,400	18.0	232,000	39.3	204,930	36.6	212,000	37.5	215,100	37.3	225,880	38.7

a. Adjustments based on crest value of 51,100 cfs
b. Estimated by Central Maine Power Co.
c. Crest on April 3, one day after North Sidney crest (two days after last forecast run)

APPENDIX 2.0 NWS FORECASTING POLICY RELEVANT TO GAGE CLOSURES

Many of these forecasts and warnings are based on USGS stream gaging information. Funding for stream-gaging operations comes from various sources, and is generally a 50-50 cooperative effort. Annually, the USGS and the funding cooperators review the stations in the stream gaging program and make determinations about which stations will be operated in the next year. Under these budgetary constraints, the USGS may consider discontinuing a station that is either an NWS forecast point or a station used as input to the forecast process.

If the NWS is notified that a gaging station that is used in the NWS Hydrologic Services Program is proposed for closure the following actions are taken:

A. The NWS verifies that the river gaging station proposed for closure is used in the Hydrologist Services Program.

B. The NWS determines, from information provided by the USGS, who is providing funding support (Federal and/or state cooperator) for the gaging station.

C. For each river gaging station used in the NWS Hydrologic Services Program that is proposed for closure, the NWS will coordinate with the appropriate USGS District Office and/or Federal and/or state cooperator stating the importance of the station and the impact of the closure on the NWS hydrologic forecast and warning operations.

D. If the current cooperator cannot continue to fund the station in question, the NWS and the USGS, will try to coordinate with other potential cooperators to seek funding support for the stream gaging station.

If efforts to keep the stream gage operational are unsuccessful, the NWS hydrologic forecast program will be severely affected. Real-time streamflow data is essential to the issuance of accurate river, flood stage, and water supply forecasts. As a result of gage closures, the NWS loses the ability to provide timely and accurate warnings and forecasts of floods for specific locations. Therefore, the NWS will be forced to discontinue the issuance of specific river forecast products for many of these sites.

The NWS Eastern Region has adopted an official policy relevant to gage closures and their effect to hydrologic services. Eastern Region Regional Operations Manual Letter E-2-95, file with E-02, The Impact of Gage Closures/Outages on River Forecast Services describes policy and procedure and is included as Attachment A1.

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EASTERN REGION

NATIONAL WEATHER SERVICE

BOHEMIA, NEW YORK 11716

Regional Operations Manual Letter E-2-95

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Subject: The Impact of Gage Closures/Outages on River Forecast Services

1. PURPOSE

The purpose of this ROML is to state regional policy on the impact of gage closures and outages on river forecast services.

2. BACKGROUND

The National Weather Service (NWS), Eastern Region (ER) prepares site-specific river forecasts for about 600 locations. In order to assure accuracy and integrity of forecast information, automated or manual real-time observed river gage data must be available on a daily and criteria basis, at a minimum, to support RFCs/NWSFOs/NWSOs in their forecast operations. The U.S. Geological Survey and other agencies that support, operate, and maintain river gages have come under increasing pressure due to budget tightening, to close stations and discontinue river gage operations. The impact of the closures may have a direct effect on river forecast operations.

The NWS has a responsibility to follow-up on proposed gage closures that affect river forecast points, and if discontinued, take appropriate action in providing a level of forecast services commensurate with data availability for the impacted river basin, or forecast point.

3. GAGE CLOSURES

Field offices should alert ER Hydrologic Services Division (HSD) upon receiving notification of proposed gage discontinuations at river forecast points. ER HSD will be the focal point to coordinate funding support for stream gaging efforts with the appropriate sponsoring agencies at the state and regional level. The affected HSA will coordinate with local sponsoring agencies. Under the direction of ER HSD, MICs/HICs should encourage continued support for the continuation of the stream gaging program by highlighting its importance in the hydrologic warning and forecast program. The Office of Hydrology (OH) will seek support for the cooperative stream gaging program at the national level.

4. REDUCED FORECAST SERVICES DUE TO GAGE CLOSURES

The ER HSD shall be responsible for evaluating the impact of the closure of a stream gaging station(s) on forecast services. The following procedure shall be followed for requesting approval for reduced forecast services as a result of gage closures or extended outages:

4.1 The NWSFO/NWSO is the office responsible for submitting requests for reduced forecast services as a result of gage closures within its Hydrologic Service Area (HSA).

4.2 The NWSFO/NWSO should send a letter to affected hydrologic users, alerting them to the possibility that forecast services may be reduced due to pending gage closures.

4.3 Prior to submitting a request, the HSA office should coordinate with the responsible RFC on any impacts the gage closure(s) will have on forecast services. RFCs should provide their written comments on any impact(s).

4.4 Options for alternative gage readings (such as, the installation of a staff gage at the gage site, and the appointment of a cooperative observer to take river observations) should be considered. Any options should be coordinated between the HSA office and the servicing RFC.

4.5 All requests for reduced forecast services due to gage closures should be made in writing by the MIC of the office with HSA responsibility to ERH HSD. Requests from offices in other NWS regions should be sent to ERH HSD through their regional HSD.

4.6 Requests should be as specific as possible. They should include technical evaluations by the servicing RFC and a copy of the letter to affected users.

4.7 The ERH HSD will coordinate an evaluation of the request with the appropriate NWS offices (RFC, NWSFO/NWSO, OH, other regional HSDs, etc.).

4.8 ERH HSD will issue a letter of authorization on the request for reduced services to the office with HSA responsibility and the appropriate RFC. Where approved, RFCs, NWSFOs/NWSOs will be authorized to issue categorical (Minor, Moderate, Major) flood forecasts, where practical, for the affected forecast points, in lieu of site-specific forecasts.

4.9 The office with HSA responsibility shall be responsible for coordinating the reduction in hydrologic services with affected hydrologic users (e.g. emergency managers, hydrologic agencies, media, etc.).

4.10 Temporary, or short-term gage outages should not be considered for reduction in services unless the outages develop into a long-term (6 months or more) duration. For short-term outages at river forecast points, site-specific forecasts should continued to be released. Public issuances should note that current data is unavailable or missing.

4-11 E-19s for forecast points that have been approved for reduced service operations should be updated by the affected HSA office.

4-12 Automatic or manual product formatters for the issuance of river flood forecasts and warnings should be updated to reflect the change in forecast services.

John T. Forsing
Acting Director, Eastern Region